E-2

METHODOLOGY

FUNDAMENTAL PROCEDURE

Fundamental Procedure for Developing a Physical Model Using Micro-model Methodology

I. **<u>Statement of Problem</u>**: The problem must be defined and study objectives stated. This includes some fairly specific qualitative descriptions of the problem or problems so the modeler can determine the applicable model limits and establish a general approach for conducting the model effort. The specific problem location is identified and described regarding one or all of the following:

Extent of problem

Inadequate Navigation Depth

Inadequate/Undesirable Channel Alignment (navigation, bridges, etc.)

Undesirable flow distribution through main channels and side channels

Environmental adaptations of existing structures

Environmental enhancement objectives

Undesirable Depositional Patterns

Bank stability/Recession

Excessive Dredging Requirements

Evaluating changes in/Effects of existing structures

Entrance and Exit conditions that may be relevant to the problem

Objectives are also outlined and include an estimate of the number of alternatives to be considered. Objectives often include defining the location of training structures, establishing general controlling elevations for the structures, and a projection of prototype channel response to proposed changes. Where existing structures are analyzed to determine their effects, goals include establishing whether modifications are required or would result in a desired outcome (e.g. where dikes are notched to provide back channel areas for environmental purposes).

II. Model Layout: Appropriate Computer Aided Drafting and Design (CADD) and digital photography files are compiled once the problem location and extent are established. These files are used for layout of the model. The physical dimensions of the micro-model flume establish maximum model dimensions. The maximum dimensions of the flume are typically 76 inches long by 35.5 inches wide. The model horizontal scale is determined by trial until the required reach fits within the flume. Consideration is also given to the minimum channel width acceptable for evaluating the particular problem under consideration. The minimum main-channel width typically used in the micro-models is about 1.5 inches. Side channels are often smaller than this minimum. However, most problems exist in the main channels and measurement of the bathymetric changes in the side channels is of lesser importance. The minimum (1.5 inches) is imposed primarily because of difficulty in measurement of changes in bathymetry that occur during alternative comparisons.

III. Model Insert - The model template, or insert, is constructed using marked up aerial photography and CADD drawing files. The modeler establishes the channel bank lines along the channel. These lines are typically located at the vegetation line or where sufficient information exists at the true top bank location. Bank lines are modified to permit adjustment of the model's banks if bank realignment is to be considered during analysis of the stated problem(s). The modified bank may consist of either of a removable section in the insert or just a setback bank line. Setback bank lines are adjusted to the correct bank lines using modeling clay during the calibration phase of the model. The clay is modified during alternative analysis to appropriately reflect proposed changes. A reference grid is established using a coordinate system such as the Universal Transverse Mercator (UTM). The UTM grid is added to the CADD file describing the model limits.

The insert is manufactured from three scaled plots of the prototype reach being modeled. These plots have bank lines and other model features such as islands, grid lines, headgates, and tailgates clearly marked. The manufacturer cuts the insert material to the specified bank lines. Insert material consists of two pieces of acrylic sheeting and a layer of high-density foam. The acrylic sheeting has two of the scaled plots laminated to their top surface. The high-density foam is laminated between the two acrylic sheets. The resulting insert has the lowest acrylic layer over the entire model extent. The foam layer and upper acrylic layers are cut to provide an open trough, or channel, in the desired location. The model channel has vertical banks, which are painted black. Black bank surfaces help prevent extraneous data from being included in surveys from 3-D laser scanning.

IV. **Model Setup** - The insert is secured within the flume using silicon caulking and woodworker's clamps. Clamps are used to prevent movement of the insert during model operations. Flume tilt is initially adjusted to a slope of approximately 0.01 feet per feet. Sediment is added to the insert to approximately one-half the insert depth. A tailgate is added to the insert to control outlet bed elevations. The modeler establishes the tailgate elevation near the insert's mid-depth. The modeler adjusts flume tilt, volume of sediment, and tailgate elevation during initial calibration of the model. Structures reflecting baseline conditions are placed at prototype structure locations.

V. **Initial Model Calibration – Constant Flow Operation** - Model calibration begins by introducing a constant high discharge (approximately at the +15 to +20 LWRP level) to the insert. The constant discharge begins to form the bed bathymetry given the channel alignment, the amount of sediment and the flume tilt. Once bed bathymetry stabilizes, the effective slope is adjusted until the water surface is parallel to a reference plane established from three coordinate points on the insert surface. The effective slope is adjusted by changing the tilt of the flume, adding sediment to or removing sediment from the model, adjusting the tailgate assembly, or a combination of all four. **The fundamental principle of micro-modeling methodology relies on the fact that the bed slope will adjust to an equilibrium condition given a specified channel alignment, sediment size, sediment size distribution, and flow. The premise is that the channel will arrive at the same slope regardless of the flume tilt or volume of sediment in the flume.** During adjustments to sediment volume and/or flume tilt, measures are added to provide the necessary flow distribution entering the model. Guide vanes, roughness, non-erodible material, and baffles are added as necessary to establish the correct inlet flow distribution. The constant discharge is varied higher and lower to determine appropriate limits for hydrograph cycles. Lower limits result when the flow produces the correct sediment movement in the model for lower flow conditions. Upper limits result when the flow produces the correct sediment movement in the model for higher flow conditions. Correct sediment movement depends largely on the modeler's judgement. Repetitive surveys of the model bed bathymetry measure the state of model calibration. Initial estimates of model vertical scale are made during beginning calibration efforts. Vertical scale determines the spread of the model data when converted to prototype coordinates. As such, a larger vertical scale (e.g. 1 inch = 50 feet versus 1 inch = 25 feet) increases the spread of the converted elevation coordinates. A shift factor determines the vertical offset between model reference plane (which is determined from three coordinate points on the model insert surface) and the model channel elevations. The shift reflects the relative difference between the established reference plane and the model's equivalent Low Water Reference Plane (LWRP). Adjusting the shift translates all model elevation data up or down during the conversion to prototype coordinates. The shift is measured in inches. The amount of adjustment that occurs in prototype coordinates depends on the selected vertical scale. Continual refinements to the shift and vertical scale continue until the model calibration data approximates the prototype data. The actual measure of how well the model data reproduces the prototype data depends on the modeler's interpretation, but is generally evaluated on how the converted model data reproduce prototype survey conditions both in general elevation and location. The effects of shift and vertical selection are best explained through example.

EXAMPLE:

____________ Model Reference Surface

____________ Model Equivalent LWRP location

Maximum model survey elevation: -1.5 inch (relative to reference plane)

Minimum model survey elevation: -2.5 inch (relative to reference plane)

The vertical distance between the model reference plane and the equivalent LWRP is estimated to be 1 inch and the vertical scale is estimated to be 1 inch = 100 feet. This translates into an adjustment of 100 feet in the vertical when the model survey data is converted to prototype coordinates. Using the shift of 1 inch and a vertical scale of 1 inch = 50 feet translates into an adjustment of 50 feet in the vertical when converting to prototype coordinates. Changing the shift to 0.5-inch results in an adjustment of 50 feet with the 1 inch = 100 feet vertical scale and only 25 feet using the 1 inch = 50 feet vertical scale. Likewise, adjusting model survey data with the 1 inch = 100 feet vertical scale would produce a spread of 100 feet vertically in prototype coordinates while the 1 inch = 50 feet vertical scale would only produce a spread of 50 feet.

VI. **Initial Model Calibration – Unsteady Flow Operation** - Unsteady operation involves operating a control valve in either a triangular or sinusoidal mode. The triangular mode operates the valve to provide a stepped valve opening sequence that results in a linear opening/closing rate between the minimum and maximum settings. The sinusoidal mode operates the valve to provide a stepped valve opening sequence that results in a sine curve opening/closing sequence. Flow does not directly influence how the valve is operated; e.g. a model hydrograph is not truly a flow hydrograph it is a valve opening sequence. In other words, valve opening establishes the flow rate. Recent utilization of flow meters provides a display of flow through the hydrograph cycle; however, valve stepping governs cycle operations at present. Cyclic model operation provides a mechanism for simulating the effects of the hydrograph cycle in the prototype. Use of the triangle cycle option provides a near sine wave response in flow to the model. The sine cycle option provides a pseudo sine wave response in flow (produces a sine shaped curve with extended peak flow periods). Refinement of the maximum and minimum limits of flow occurs during model calibration. Finalization of the shift and vertical scale generally occurs during unsteady flow operations. After final shift and vertical scales are determined, water surface elevations are checked with constant discharges. The water surface elevations are checked at low and high flow limits to determine the prototype stage conditions being modeled. Current procedures typically limit maximum model flows to produce a +15 or +20 LWRP in the prototype. Typical minimum model flows tend toward 0 LWRP or slightly lower. The upper flow bound results because operation of the models over larger limits causes non-uniform distortion of the energy grade line in the model. The higher flows produce much higher energy in the micro-model and tend to cause excessive sediment movement. Entrance and exit conditions are modified slightly if necessary to improve the model's ability to reproduce the prototype surveys. Addition of non-erodible materials to the model is considered when model conditions can not reproduce very unusual prototype conditions. Follow-up field reconnaissance lends support to use of such non-erodible materials. The non-homogeneous nature of depositional features within channels results in many unusual scour and depositional trends in the prototype. Prototype structures are reset to the appropriate elevations using the finalized shift and vertical scale.

VII. **Final Model Calibration** - The model is operated for several hydrographs to verify that the bed forms are in equilibrium. The definition of equilibrium generally refers to a state where the bed sediments move in a uniform manner throughout the cycle of operation. No sediment waves appear in the model at equilibrium. Evaluation of the equilibrium condition depends on the modeler to some degree. Structure elevations and positions are checked and verified. The modeler surveys the model bathymetry and converts the model data to prototype coordinates. Plots of the model bathymetry over the model reach are compared to prototype surveys. General trends (e.g. deeper areas, thalweg location, shallower areas, and crossing locations) are compared to the prototype surveys.

Operation of the model through several iterations of the above cycle, flow hydrograph through comparison of surveys, provides a reasonable assurance that model results are repetitive and that the model is indeed at a point of equilibrium. Consistency between repetitive model surveys and their comparison to prototype surveys govern when model baseline conditions have been attained. Development of the baseline conditions is paramount to successfully completing the remainder of model study efforts.

VIII. **Flow Visualization** - Flow visualization in the model attempts to identify velocity streamlines of surface flow conditions. Where prototype data are available, flow visualization provides a positive reassurance that flow conditions in the micro-model resemble prototype flow conditions. Prototype data consist of aerial photography containing ice-flows or possible float data obtained through surface velocity and path measurements. Often, this data is lacking or is difficult to obtain, particularly in warmer climatic regions. Flow visualization utilizes timed exposures to record the paths of "floaters" or surface confetti. Floaters actually float on the surface of the model and closely track the flow path. Surface velocities in the model are not estimated from the timed exposures at present. Flow visualization provides a means to compare model surface flow paths to the prototype flow paths and serves as a mechanism for comparing flow paths resulting from alternative designs back to the baseline model. The timed exposures utilize a constant flow rate for each series of photographs. Photography obtained at various flow rates provides a method for verifying and comparing model flow conditions at different points in the hydrograph cycle.

IX. **Alternatives** - Alternative analysis begins after establishment of model baseline, or calibrated, conditions. The modeler prepares alternative design strategies and confers with pertinent technical personnel as necessary to reach stated study objectives. Proposed designs consist of possible structure locations, alignments, lengths, and elevations. Each proposed design is placed within the model. The model is operated through several repetitive hydrograph cycles with the proposed structures in place. The actual number of hydrograph cycles depends on the relative magnitude of the changes induced by the alternative structures. Slight changes resulting from minor structural elements may require less time for the model to restabilize the bed. More drastic changes due to more extensive structural elements may require increased operation times before the model restabilizes the bed. Bed restabilization occurs when the model bathymetry obtains a new equilibrium condition. The new equilibrium condition results when bed material transport remains relatively consistent over several hydrograph cycles and when no sediment waves are observed in the model. Again, modeler judgement determines when the model attains the desired equilibrium. A survey of model bathymetry is taken of the resulting equilibrium condition. Conversion of the model bathymetry to prototype coordinates facilitates comparison of each alternative condition to the baseline model condition.

Each alternative condition is prepared and operated as outlined above. Surveys for each alternative are in-turn compared to the baseline model condition. Consultation with technical customers continues throughout the evaluation of alternative designs. Each successive alternative design incorporates information gained from previous alternatives. Often add-on alternatives result from discussions with the client. These additional alternatives attempt to balance projected prototype response with desired engineering and environmental desires.

X. **Report** - A comprehensive report documents micro-model study efforts and findings. Each report follows a specified structure and format. Each report documents the pertinent background of the study reach and clearly identifies the problems and objectives for the study. Individuals supplying information, data, or basic knowledge about the reach are acknowledged. Micro-model extent, horizontal and vertical scales and a distortion ratio are documented. The final vertical scale and selected horizontal scale determine the distortion ratio (which is the ratio of the horizontal scale to the vertical scale). The type of sediment material used in the model is also documented. Alternative designs are described in sufficient detail for proceeding to the next level of design. The next design level involves proposing structural modifications recommended by the micro-model study to a review panel for discussion and approval. Design then proceeds by developing a plan of implementation. Construction may be phased over several construction seasons, depending on the magnitude of changes proposed and potential prototype response.

KEY PARAMETERS & DATA FROM PREVIOUS STUDIES

1. Initial Flume Tilt/Slope.
2. Final Flume Tilt/Slope.
3. Sediment size and gradation.
4. Maximum flow rate used in the model.
5. Minimum flow rate used in the model.
6. Hydrograph Cycle type (e.g. triangle, sine) and duration.
7. Constant flow rate(s) used for initial model setup and for flow visualization photography.
8. Correlation/Evaluation criteria used for verifying model survey data to prototype data.
9. Number of cycles model operated between repetitive surveys for consistency checks.
10. Number of cycles model operated between alternative runs.
11. Starting conditions for each successive alternative model run.
12. Similitude criteria for flow, sediment transport, time, and surface tension.
13. Water surface elevations for model operation, Maximum and minimum.
14. Shift used for model data conversion to prototype coordinates.
15. Reference coordinates used on Insert.
16. Shift and vertical scales used during initial model setup.
17. Shift and vertical scales used for calibrated model (almost same as #14)
18. Suspended Sediment materials

19. Horizontal scale
20. Min/max size of channels
21. Flow rate
22. Time and budget allowed
23. Sediment Flow through model during cycle operation and at constant flow.